Quarterly Progress Report #10

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Quarter 10: January 1, 2002-March 31, 2002

Neural Prosthetic Control

NINDS CONTRACT NUMBER: N01NS92322

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This Quarterly Report reports on progress in interface development, and more specifically, online closed-loop neural control, which was successfully achieved this quarter. First there is a summary of the overall objectives of the contract of the project, followed by a description of recent progress in interface development.

1. Introduction

A number of neurological disorders, such as spinal cord injury, MD and ALS result in the inability to make voluntary movements. A major reason for paralysis in these disorders is a disconnection of the signal from a normal brain from the spinal cord or muscles. Devices that can detect and decode motor commands have the potential to restore voluntary actions in these individuals. The purpose of this project is to demonstrate the ability to use neural signals to control real world devices in monkeys; such devices can ultimately serve as prosthetic aids for paralyzed individuals.

Control signals for prosthetic devices can be derived from a number of sources, including the eyes, muscles, and EEG. These signals are, however, rather limited in the number of dimensions they can control. Going beyond a one dimensional control signal is difficult and often interferes with natural behavior. For example, two dimensional EEG control requires full attention to control without distraction (such as gaze shifts). By contrast, populations of neurons appear to contain rich signals, potentially able to control multiple dimensions independently. However, chronic recording of multiple neurons in primates has been technically challenging, the ability to decode neural activity into meaningful control signals is poorly understood and the ability to control devices using such signals is not developed.

The overall goal of this work is to develop a means to bring a robotic arm under near real time neural control using a multineuron signal derived from a recording device that is chronically implanted in a macaque monkey motor cortex. This project has three specific objectives. The **first objective** is to develop and test technologically advanced neural recording devices in a non-human primate model. This work examines the stability, efficiency and biocompatibility of electrode arrays and the suitability of the primary motor cortex as a sight to obtain neural recordings. Once recorded, neural activity must be decoded into meaningful control signals. The optimal methods for such decoding are not obvious. A **second objective** of the project is to examine various decoding methods and evaluate their ability to be useful control signals. This requires mathematical tools and signal processing that reconstructs intended actions from abstract, neurally based motor commands generated in the cortex. This aspect of the project involves fundamental motor control questions, such as what coordinate system is used to encode voluntary actions. **A third objective** of this project is to show that such signals can be used to control devices such as a robotic arm or a computer interface. These devices serve as a proxy for the lost limb and can be used to recreate useful actions like those intended for the arm. Successful completion of these goals would suggest that this approach could be used to restore movement in paralyzed humans.

2. Summary of Related Achievements this quarter

We re-implanted a Neuroport (Bionics, LLC) array in monkey(99-2) this quarter and implanted head restraint bolts in one more monkey (99-12) in preparation for later array implantation. This Neuroport array implant also failed because the glue bonding of the connector plate failed. 13/96 cells showed modulation when we stimulated the electorodes, but the recording quality is very poor. We will again plan to explant this array, let the animal heal, and then re-implant at a later time. Real time control of a computer cursor by a monkey was achieved and a manuscript on this finding was published in Nature (Serruya MD, Hatsopoulos NG, Paninski L, Fellow MR, Donoghue JP. (2002) Instant neural control of a movement signal. Nature 416:141-142).

3. Interface development

The goals of this aspect of the project are (3.1) to develop interfaces with peripheral devices (i.e., robot arm, computer), (3.2) demonstrate that decoded neural signals can be used to control such peripheral devices, and (3.3) demonstrate that monkeys can bring this signal under near real time control. In this quarter we completed offline analyses showing that a robot arm or computer cursor can be used to mimic actual hand motion using data processed offline. During this quarter we also tested the ability for a monkey to control a device using neural signals to substitute for hand motion.

3.1 Interface with peripheral devices.

We have designed interfaces that allow decoded neural signals to be used as a control input to other devices. An interface that couples the signal to a PC is complete and work is ongoing to complete an interface with a CRS robot. The output of Labview programs was successfully coupled to the CRS robot arm to provide a command signal to the controller box.

3.2 Offline control of prosthetic devices:

We are continuing to investigate methods to overcome difficulties in trying to update the robot position at appropriate time intervals using the CRS robot. The CRS robot position control hardware is designed with a speed control that must processed at each position update. This is time consuming and generally useless since the properties of the arm and the rapid updating (~100 ms) make it reasonable to simply move the arm at each step at its maximum speed. The robot’s hardware interface appears to create delays and variability in executing instructions.

3.3 Real time control of prosthetic devices:

During this period we trained a monkey to use the two-dimensional linear filter reconstruction signal based on neural signals from MI to acquire targets displayed on the video monitor. We also began training a second monkey at this task. Filters were built rapidly using neurons recorded in real time and the monkey was able to use the signal immediately to control cursor motion. The monkey did not receive any visual feedback about his actual hand position: only the predicted hand position from neural activity was displayed. Whereas Euclidean distance and correlation coefficients are suitable for measuring how well linear filters reconstruct actual trajectories in offline analysis, measuring neuroprosthetic use in a closed-loop system calls for measures that pertain directly to functional utility. We chose a task in which stationary targets would appear at a random position on the screen and the animal had to move the cursor to the target to receive a reward and be presented with the next target. We found that the time-to-target (time from appearance of target to acquisition of target) was a helpful functional measure: the time-to-target using neural control was not statistically significantly different from time-to-target with manual control by a one sided Kologorof-Smirnof one-sided test (alpha = 0.05). In addition to controlling the cursor, the prediction signal was also used to control a remotely located F5F3 robotic arm (CRS Robotics) using two LabView programs coupled by the ethernet. We successfully implemented ~real-time control of the robotic arm from a neuroprosthetic algorithm signal.

During the current contract period we also published the real time control and neural reconstruction findings in a brief report, "Instant Neural Control of a Movement Signal", Nature 416: 141-142. and two reports on reconstruction are under review. We have continued training a second subject in preparation for the neural control task, and plan to start testing the system in the next quarter. During this quarter we further improved the real time control system largely by the efforts of Mijail Serruya and Daniel Morris, a former undergraduate in the lab and now a computer science graduate student at Stanford. The new system, streamlined in Matlab, runs more efficiently than the previous version and notably allows a modular approach to test different algorithms, which can be written entirely in Matlab.